Large Scale Ocean Observations Using Submarine Cables: Toward an Extended Observational Network

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Goal: *To complement traditional ocean observations by seafloor cables as sensors of transport and temperature.*

The transport of heat by ocean currents is an important component of the Earth's climate system. Observations of ocean transports and their variability are therefore important for improved understanding of natural fluctuations and climate change.

Submarine cables offer possibilities of sensing large scale integrals of both transport and seafloor temperature. Their spatial integration, temporal continuity, and potentially long duration provide measurements highly complementary to the sampling strategy of most other oceanographic measurements, many of which measure only part of the flow field, and most of which are highly intermittent in space, time, or both.

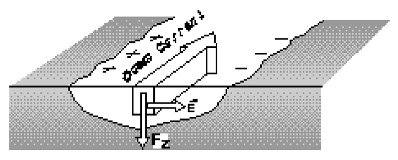
Large scale integrals observed with cables can be used:

- As ocean climate and circulation indices.
- To put temporally intermittent measurements in the context of long, homogeneous and continuously resolved time series.
- To test the spatial scale of fluctuations seen in point-measurement time series (e.g. moorings, regularly occupied hydrographic stations).
- To contribute to the set of measurements available to constrain numerical models of the ocean, evaluate and improve generation circulation models.

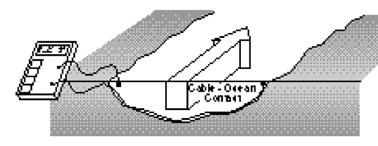
Accomplishments:

1. Transport variability from cable voltages

Motional Induction



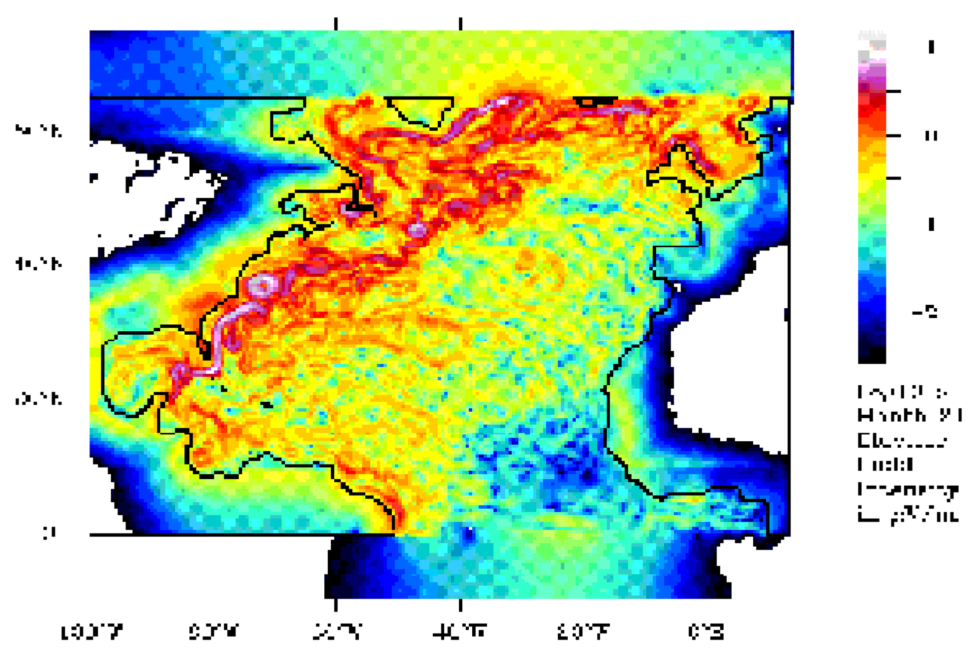
Motionally induced voltage differences arise when the electrically conducting ocean moves through the Earth's magnetic field. For large scale, slowly varying ocean currents, to first order the ocean is surrounded by insulators, and Ohm's law for a moving medium is satisfied by electric charge buildup until the cross-stream electrostatic forces balance the depth-integrated force due to the seawater's motion across the geomagnetic field. In the sketch, Fz is the vertical component of the geomagnetic field and E is the cross-stream electric field.



Seafloor cables with endpoints in contact with the local ground or seawater can be used as voltmeter leads to sense motionally induced voltage differences in the ocean.

Numerical model of motional induction in the North Atlantic (with J.T. Smith and J.C. Larsen)

At the beginning of this work, the favorable results of voltage-based transport monitoring in the Straits of Florida were widely thought to result from special and relatively rare circumstances. There were a number of concerns, which had not proved easy to evaluate by analytical calculations or simplified numerical models. Realistic bathymetry, sediment thickness and electric conductivity, seawater temperature and salinity variability, all needed to be modeled and the implications for practical voltage measurements assessed.

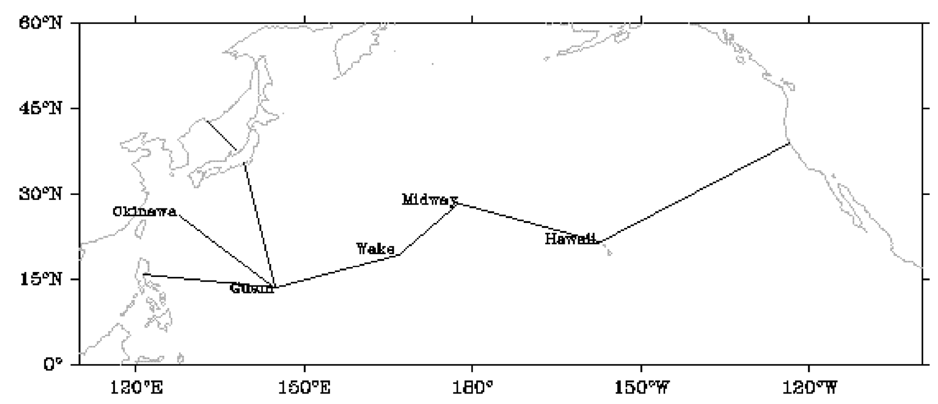


North Atlantic electric field intensity in the final month of the numerical model of Flosadottir et al. (1997a,b).

The model is based on the WOCE Community Model first experiment, three-dimensional Earth conductivity models, the International Geomagnetic Reference Field, and seabed sediment thickness from seismic data and a generic sediment conductivity model. Colored areas on land are due to electric currents.

The results of the simulation show a linear relationship between volage and net transport for many long cables in the model North Atlantic, indicating that complicating effects are less prevalent than had previously been feared. The main result of this work has been to show that a highly linear relationship between voltage and net cross-cable mass transport can prevail over large distances, even with complex flow patterns, realistic topography and earth models.

Data analysis and numerical modeling in progress



Pacific voltage monitoring network,
Collaboration U. Tokyo, Bell Laboratories, WHOI

Numerical model of induction by tides, oceanographic and geophysical applications
Collaboration with Cambridge, Frankfurt, and Lisboa Universities

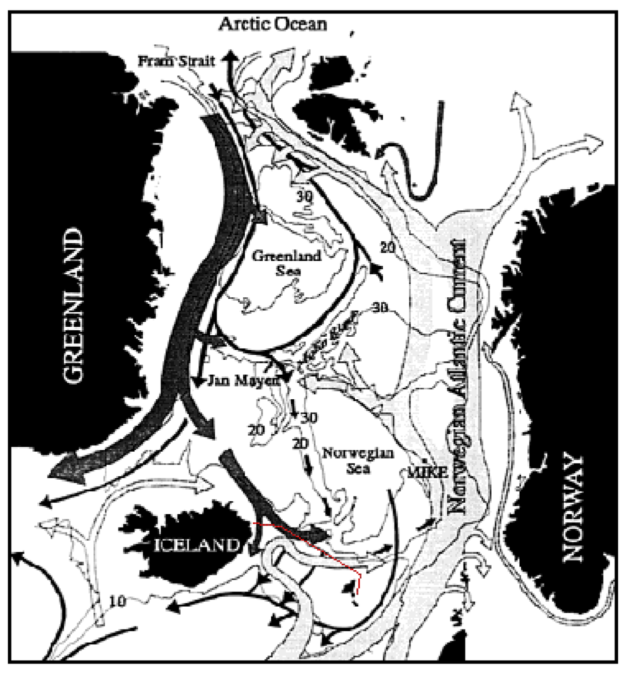
2. Average seafloor temperature from cable resistance

Historical Data

The resistance of copper wire varies with the temperature of the metal. Since a long cable may be regarded as the sum of the cable's segments in series, and since the variation of seabed temperatures is small enough for the resistance to follow the temperature of each segment close to linearly, the electric resistance of seafloor communication cables varies approximately linearly with the average bottom temperature along the cable route. Seasonal variability of cable resistance due to ocean temperature variations has been known from the earliest day of communication by submarine telegraph cables, dating back to the 19th century.

Two views of the frigate Tordenskiold, off the east coast of China and landing the first telegraph cable at Deep Water Bay in Hong Kong on October 20, 1870. After "From dots and dashes to tele and data communications", published by GN Great Nordic, Copenhagen, on the occasion of the 125th anniversary of Greath Northern Telegraph Company, June 1, 1994.

The complete cable system of Great Northern Telegraph Company in June of 1894, shown in red. The most important connecting cables shown in black.

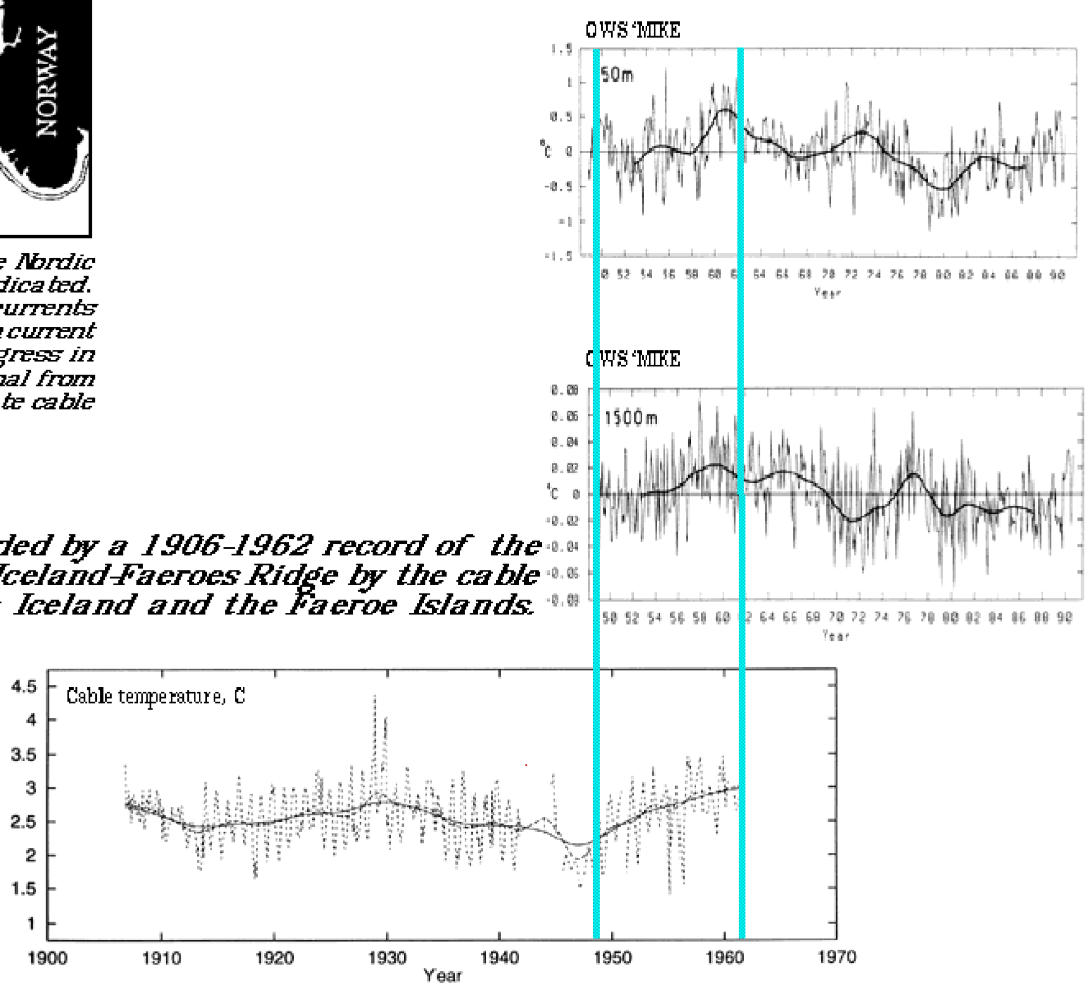


Schematic of the principal currents of the Nordic Seas with the position of OWS 'MIKE' indicated. Open hatched arrows indicate surface currents while black arrows indicate the deep/bottom current pattern. After Dickson et al, 1996, Progress in Oceanography, vol. 38, pp. 241-295, original from Osterhus and Gammelsrod. The approximate cable route is overlaid in red.

Evidence relevant to our understanding of the ocean's role in the interdecadal climate variations associated with the decadal to centennial component of the North Atlantic Oscillation (NAO) is largely based on a handful of long time series in combination with large scale analyses of atmospheric and sea surface patterns. To cover a full cycle of the decadal-centennial variability it is necessary to go back at least to the early years of the 20th century. However, most ocean time series started only in the post WWII period, and analyses based on large scale collections of ship observations have difficulties bridging the mid-century for reasons that include data gaps, changes in observation methods at sea, and in patterns of shipping.

A possible contribution is provided by a 1906-1962 record of the resistance of a cable along the Iceland-Faeroes Ridge by the cable operators of Great Northern in Iceland and the Faeroe Islands.

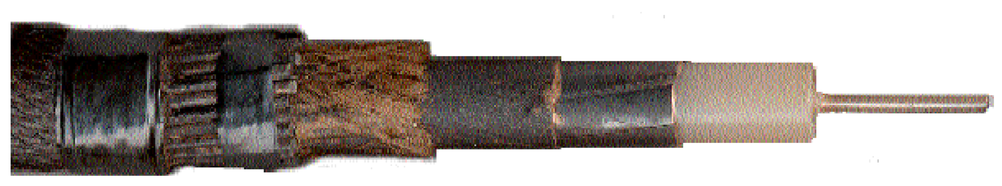
Comparing the weather ship record and the cable time series from the late 1940s to the early 1960s, when the two time series overlap, both show a rise in temperature over the '50s, followed by a leveling off at the beginning of the '60s. Comparison with other data sets and numerical models is in progress.



Upper two panels: Monthly means of temperature at 50 m (representing the surface layer 0-300 m) and 1500 m at OWS Mike, 1950 to the beginning of the 1990s. After Gammelsrod et al., ICES mar Sci. Symp., 195: 68-75, 1992.

Bottom panel: Average temperature along the cable route (0-800 m depth), derived from the cable resistance data, 1906-1962.

Future Directions:



Proposed/planned Observational Work

North Atlantic subtropical gyre and thermohaline circulation seasonal - decadal transport variability

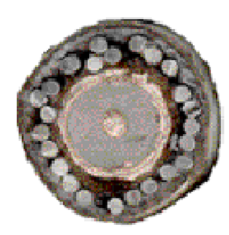
- *Eastern branch of subtropical gyre, Madeira to Lisbon, Collaboration U. Lisbon, U. Frankfurt, Cambridge University*
- *Gulf Stream, Deep Western Boundary Current and recirculations, New York to Bermuda*
- *Caribbean inflow, Grenada Passage, Collaboration U. Miami and AOML*
- *Florida Current – the next decade. Collaboration PMEL and AOML*

Temperature time series from cable resistance measurements

Historical Data
- *Extend analysis to Shetland-Faeroes cable,*
- *Search for further historical data*

New Measurements
- *East Caribbean Fibre System's Grenada Passage first opportunity*

Modern cable laying – from Great Northern



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PMEL 1998 Program Review - http://www.pmel.noaa.gov/98 prog_agenda.html